Automated Synchrotron X-ray Diffraction of Irradiated Reactor Pressure Vessel Steels

PI: Lynne E. Ecker- Brookhaven National Laboratory

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Collaborators: Erich Dooryhee, Sanjit Ghose- Brookhaven National Laboratory
G. Robert Odette- University of California, Santa Barbara

ABSTRACT:

This project will develop an automated system to rapidly and safely acquire synchrotron data on radioactive samples. Data will be obtained on irradiated Reactor Pressure Vessel (RPV) steels, austenitic stainless steels and ferritic-martensitic steels that will improve the understanding and performance predictions of these materials in nuclear reactor environments. RPVs serve as the primary containment for Light Water Reactors (LWR) and are subject to long-term, high-temperature (300 oC) and irradiation conditions during reactor operations. Austenitic stainless steels, such as 304 and 347, are frequently used for core internals such as core barrels, bolts and support plates. Ferritic-martensitic steels such as T91 and HT9 are being considered as structural materials in advanced nuclear reactors. Exposure to radiation in a nuclear reactor can cause changes in the microstructure of the steels that can lead to brittle fracture, fatigue or irradiation-assisted stress-corrosion cracking. Radiation induced segregation can make the material prone to phase-transformations and new phases are observed (precipitation of Ni-enriched G phase silicide in austenitic stainless steels or Mn-Ni-Si Late Blooming Phases in RPV steel). In addition, the accumulation of defects (vacancy clusters) or helium can lead to void formation and swelling. Because of the importance of these problems, the U.S. has performed and is continuing to support, irradiation test programs at facilities such as Advanced Test Reactor – National Scientific User Facility (ATR-NUSF). Large numbers of samples (thousands) with varying chemistries, grain sizes, cold-work condition and dose are currently in repositories. By using a robot, structural information such as the phases, and size, shape and distribution of nano/micro-structures such as voids and fine precipitates that form during irradiation will be acquired on a statistically significant portion of samples.

The research will utilize the X-ray Powder Diffraction (XPD) Beamline at the National Synchrotron Light Source-II. NSLS-II will be a new state-of-the-art, medium-energy electron storage ring designed to deliver world-leading intensity and brightness. The primary purpose of the XPD beamline is the quantitative characterization of the atomic structure of complex materials; not just carefully prepared ideal systems, but materials as they are actually used. A robot will be available at XPD that can acquire high-resolution x-ray diffraction data (HRXRD), high energy (high Q) data for Pair Distribution Function Analysis (PDF), medium angle x-ray scattering data (MAXS with resolution 1-100nm) and X-ray tomography (CT). This research proposes developing the hardware which will extend the capabilities of the robot to handling nuclear materials. This includes: sample holders (which will also serve as containment), a custom magazine that dispenses the samples to the robot, the robot end effector (gripper specific for the sample holder) and on-line remote monitoring and aligning capabilities. This suite of custom accessories specifically designed for radioactive materials will also be available to the entire nuclear materials science community through a competitive proposal process at the NSLS-II.

This research will produce two very significant outcomes. The first is that it will develop an innovative new tool that can address a gap in nuclear materials research by providing greater access to synchrotron data to the entire nuclear community. The proposed tool will enable the safe, unmanned manipulation of relatively large numbers of radioactive samples for statistically representative, high-throughput measurements. The capability is truly crosscutting and will impact the DOE mission to develop fuels and structural materials. The robot will enable combinatorial structural methods to be applied to a wide range of nuclear materials (metals, ceramics and coatings). The second outcome is a direct contribution to the understanding of aging in steel and a significant addition of data to material databases that can be used for materials modeling.